Implementation of hypoplastic granular interface models using FRIC subroutine

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1 Introduction

When using implementations from soilmodels.info in your research, please cite it as: G. Gudehus, A. Amorosi, A. Gens, I. Herle, D. Kolymbas, D. Mašín, D. Muir Wood, R. Nova, A. Niemunis, M. Pastor, C. Tamagnini, and G. Viggiani. The soilmodels.info project. International Journal for Numerical and Analytical Methods in Geomechanics, 32(12):1571-1572, 2008. (Gudehus et al. 2008) and the related papers referring to the frictional subroutine.

2 Sand interface model

The hypoplastic sand interface model is an enhanced form of the model from Arnold and Herle (2006) by Stutz et al. (2016). The hypoplastic interface formulation is based on reduced stress and strain tensors. The model uses the UMAT based on the hypoplastic soil model from von Wolffersdorff (1996) as a constitutive driver. The model incorporate the intergranular strain extension from Niemunis and Herle (1997) that can be used for interfaces.

2.1 Clay interface model

Will be coming soon.

3 Implementation

The implementation procedure is described in Stutz et al. (2017). The FRIC subroutine is used for calling and transformation of input and output using the UMAT implementation with a simple coding interface. The short version of the implementation is shown in the following Figure 1. Using this procedure the same parameter set could be used as a first

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approximation than for the soil continuum.

4 Input parameter

The input parameter used in the FRIC subroutine is introduced in the following. It is important to use **26 Parameters for granular interface**. The correct amount of properties (NPROPS) must be used, otherwise the subroutine will stop.

4.1 Sand interface model

The parameters and the property input to the subroutine have the same order than the UMAT. The description are taken from the soilmodels.info project webpage. In addition three additional parameters are introduced, for the sake of completeness all parameter inputs are listed:

PARAMETERS Basic hypoplastic interface model for sand

- **Parameter 1**: φ_c critical state friction angle
- **Parameter 2**: p_t shift of the mean stress due to cohesion. The effective stress $\boldsymbol{\sigma}$ used in the model formulation is replaced by $\boldsymbol{\sigma} - \mathbf{1}p_t$. Non-zero values of p_t are needed to overcome problems with stress-free state. If $p_t = 0$ it will replaced by a default value of 1 kPa.
- **Parameter 3**: h_s granular stiffness
- **Parameter 4**: n stiffness exponent
- **Parameter 5**: e_{d0} minimum void ratio at zero pressure
- **Parameter 6**: e_{c0} critical void ratio at zero pressure
- **Parameter 7**: e_{i0} maximum void ratio at zero pressure
- **Parameter 8**: α control the dependency of the peak friction angle φ_p on the relative void ratio
- **Parameter 9**: β influences the size of the response envelop (bulk and shear stiffness)

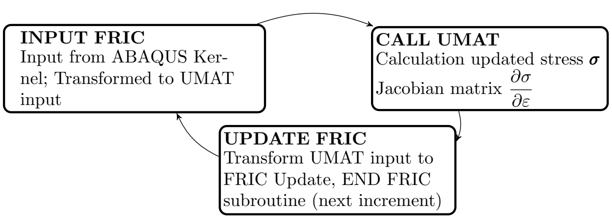

Figure 1: Short implementation version of hypoplastic interface model with FRIC routine

Parameters for the intergranular strain extension:

- **Parameter 10**: m_R Parameter controlling the initial (very-small-strain) shear modulus upon 180° strain path reversal and initial loading
- **Parameter 11**: m_T Parameter controlling the initial shear modulus upon 90° strain path reversal
- **Parameter 12**: R The size of the elastic range (strain space)
- **Parameter 13**: β_r Control the rate of degradation of the stiffness with strain (together with the next parameter χ)
- **Parameter 14**: χ Control the rate of degradation of the stiffness with strain (together with the last parameter β_r)
- **Parameter 15**: not used
- **Parameter 16**: initial void ratio corresponding to the zero mean stress e_0 or initial void ratio e. If $Props(16) < 10$, e is calculated from the mean stress p and from $e_0 = Props(16)$ using Bauer formula. If $Props(16) > 10$ then $e = Props(16) - 10$.
- **Parameter 17-22**: initial values of the intergranular strain tensor $\boldsymbol{\delta}$ in Voigt notation (δ_{11},δ_{22},δ_{33}, $2\delta_{12}$,$2\delta_{13}$, $2\delta_{23}$)

Interface parameters

- **Parameter 23**: κ_r. the surface roughness coefficient that is the ratio of residual interface friction angle to critical state friction angle
- **Parameter 24**: d_s^v virtual shear zone thickness
- **Parameter 25**: Contact dimension, Plane strain model = 2; Fully 3D model = 3, not implemented yet.
- **Parameter 26**: Steps which should not be calculated with hypoplastic interface model (Not activated). If $Par(26) > 1$ then Steps which will be neglected are $Par(26) - 1$

The state variables are defined as:

STATE VARIABLES

- **Parameter 1-6**: values of the intergranular strain tensor $\boldsymbol{\delta}$ in Voigt notation (δ_{11},δ_{22},δ_{33}, $2\delta_{12}$,$2\delta_{13}$, $2\delta_{23}$)
- **Parameter 7**: void ratio e
- **Parameter 8**: not used
- **Parameter 9**: Effective mean stress p
- **Parameter 10**: Number of evaluations of the constitutive model in one global time step (postprocessing only)

- **Parameter 11**: Mobilised friction angle $\varphi_m ob$
- **Parameter 12**: Normalized length ρ of the intergranular strain tensor $\boldsymbol{\delta}$
- **Parameter 13**: Suggested size of the first time step
- **Parameter 14-19**: free
- **Parameter 20**: Mean inplane stress σ_p for interface this is a state variable, in UMAT tensor it is equal to σ_{22} and σ_{33}
- **Parameter 21**: free
- **Parameter 22**: $\sigma_{12} = \tau_x$
- **Parameter 23**: $\sigma_{13} = \tau_y$
- **Parameter 24**: Shear strain γ_x for postprocessing
- **Parameter 25**:Shear strain γ_y for postprocessing
- **Parameter 26-27**: free
- **Parameter 28**: Normal strain ε_n
- **Parameter 29**: Normal stress σ_n
- **Parameter 30**: free
- **Parameter 31**: Number of increment in current step (debugging purpose)

5 Trouble shooting

- Intergranular strain concept:
  It is not been tested at the moment.
- 2D and axial-symmetric simulations:
  The interface model is currently only available for 3D simulations.
- Use of d_s^v:
  The inappropriate use of the shear thickness parameter can lead to non-convergence.

References

Arnold, M. and I. Herle (2006). Hypoplastic description of the frictional behaviour of contacts. In H. Schweiger (Ed.), *Numerical Methods in Geotechnical Engineering*, pp. 101–106.

Gudehus, G., A. Amorosi, A. Gens, I. Herle, D. Kolymbas, D. Mašín, D. M. Wood, A. Niemunis, R. Nova, M. Pastor, C. Tamagnini, and G. Viggiani (2008). The soilmodels.info project. *International Journal for Numerical and Analytical Methods in Geomechanics 32*(12), 1571–1572.

Niemunis, A. and I. Herle (1997). Hypoplastic model for cohesionless soils with elastic strain range. *Mechanics of Cohesive-Frictional Materials 2*(1997), 279–299.

Stutz, H., D. Mašín, A. Sattari, and F. Wuttke (2017). A general approach to model interfaces using existing soil constitutive models application to hypoplasticity. *Computers and Geotechnics 87*, 115–127.

Stutz, H., D. Mašín, and F. Wuttke (2016). Enhancement of a hypoplastic model for granular soil-structure interface behaviour. *Acta Geotechnica 11*(6), 1249–1261.

von Wolffersdorff, P. A. (1996). Hypoplastic relation for granular materials with a predefined limit state surface. *Mechanics of Cohesive-Frictional Materials 1*(3), 251–271.

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